SYNOPSIS

Operators and Measures on Cubic Intuitionistic Fuzzy Sets and their Applications in Image Processing

By

Priyadharshini. M

20PHMAF001

Supervisor

Dr. D. Jayanthi

Assistant Professor (SG) & Head (i/c)

Department of Mathematics

Submitted to

Avinashilingam Institute for Home Science and Higher Education for Women

Coimbatore - 641 043

November 2024

Operators and Measures on Cubic Intuitionistic Fuzzy Sets and their Applications in Image Processing

Introduction

The concept of fuzzy sets, developed by Zadeh (1965), provides a framework for representing and handling vague or imprecise information. Fuzzy set theory has applications in areas where precision is difficult to achieve, such as decision-making, control systems, and artificial intelligence.

Building on this foundation, Atanassov (1986) introduced intuitionistic fuzzy sets, a generalization of fuzzy sets that incorporates both degrees of membership and non-membership. This makes intuitionistic fuzzy sets valuable in handling uncertainty and ambiguity, making them useful in a wide array of applications, including medical diagnosis, pattern recognition, data analysis, computational intelligence, neural networks, and soft computing.

Further extending the concept, Atanassov and Gargov (1989) proposed interval-valued intuitionistic fuzzy sets, where both membership and non-membership degrees are represented as intervals. This representation captures greater uncertainty and has found applications in fields such as image processing, pattern recognition, cluster analysis, approximate reasoning, and complex decision-making scenarios.

Jun et al. (2012) introduced the idea of a cubic set, which is a two-component system designed for describing data using both a fuzzy interval and a fuzzy number. Cubic sets have received extensive attention in the literature and have been explored by various researchers due to their significance in diverse areas. Cubic sets are classified as internal and external cubic sets. In addition to the operations P(R)-union and P(R)-intersection, they examined the concepts of P(R)-order cubic sets. A non-membership degree corresponding to a membership degree is not included in the record for cubic sets.

To address these limitations, Kaur and Garg (2018) developed the concept of cubic intuitionistic fuzzy sets, a generalization of cubic sets that includes both membership and non-membership degrees. They discussed the concepts of P-order and R-order in cubic intuitionistic fuzzy sets as well as the operations P(R)-union, P(R)-intersection, P(R)-addition, and P(R)-product. They also classified cubic intuitionistic fuzzy sets as internal and external cubic intuitionistic fuzzy sets. When dealing with complex decision-making scenarios, a cubic intuitionistic fuzzy set works as an effective tool.

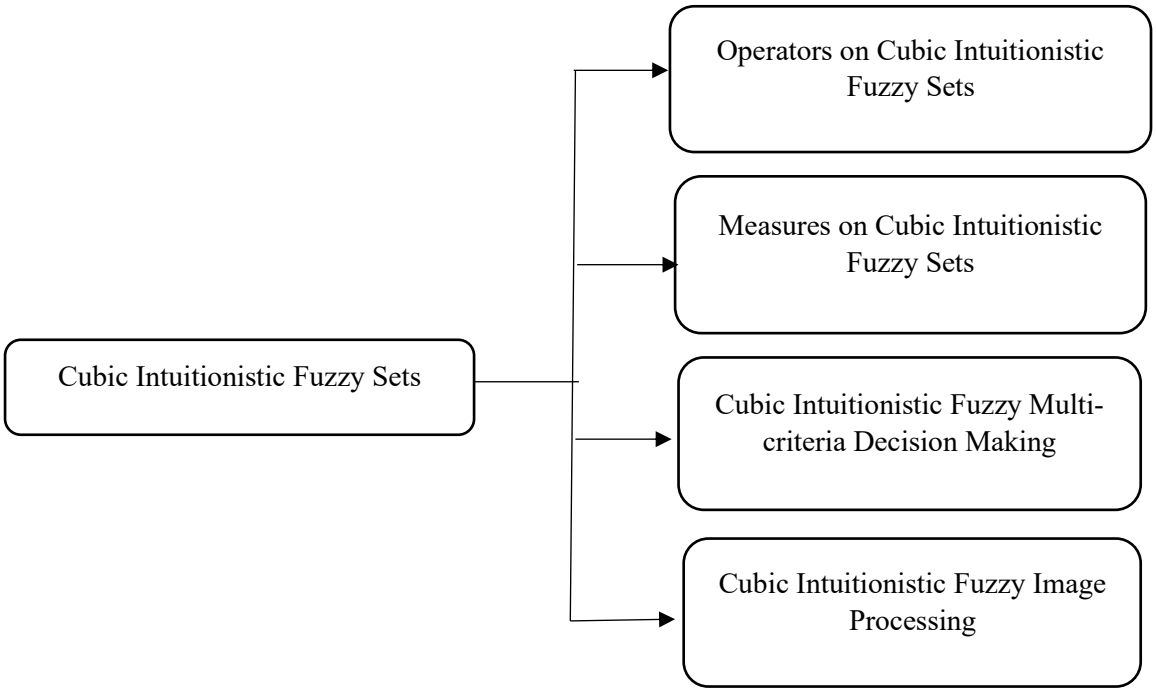
In this research work, two main concepts, operators and measures on cubic intuitionistic fuzzy sets are discussed. Two types of operators such as modal operators and linguistic hedges and three types of measures such as cardinality, entropy and similarity are defined and developed. These operators and measures are used in multi-criteria decision making and image processing.

METHODOLOGY:

- Define and develop operators and measures.
- Validating them through theoretical proofs.
- Applying them in multi-criteria decision-making and image processing.
- Comparative study between intuitionistic fuzzy sets, interval-valued intuitionistic fuzzy sets, and cubic intuitionistic fuzzy sets.

PROFILE OF THE PRESENT WORK:

The key concepts discussed in this thesis are illustrated in the following diagram.


Cubic Intuitionistic Fuzzy Sets
Operators on Cubic Intuitionistic Fuzzy Sets
Measures on Cubic Intuitionistic Fuzzy Sets
Cubic Intuitionistic Fuzzy Multi-criteria Decision Making
Cubic Intuitionistic Fuzzy Image Processing

The thesis is structured into five chapters, as detailed below:

CHAPTER 1

Chapter 1 is divided into six sections that cover preliminary definitions and existing results on various measures and operators on intuitionistic fuzzy sets, interval-valued intuitionistic fuzzy sets, intuitionistic fuzzy image processing, and cubic intuitionistic fuzzy sets, all of which form the foundation for this analysis.

CHAPTER 2

Chapter 2 is organized into three sections. Section 2.1 provides a brief introduction to various types of operators on intuitionistic fuzzy sets and interval-valued intuitionistic fuzzy sets. In Section 2.2, several operators and modal operators are developed, and their properties are discussed on cubic intuitionistic fuzzy sets. Section 2.3 defines linguistic hedges in terms of operators on cubic intuitionistic fuzzy sets and proposes related properties.

CHAPTER 3

Chapter 3 is organized into four sections. Section 3.1 provides an introduction to measures on intuitionistic fuzzy sets and interval-valued intuitionistic fuzzy sets. In Section 3.2, the cardinality measure on cubic intuitionistic fuzzy sets is defined, and several properties are established. Section 3.3 introduces a new axiomatic definition of entropy on cubic intuitionistic fuzzy sets, defines various types of entropy measures, including the entropy measure based on distance measures. A numerical example demonstrates the reasonableness of these newly proposed entropy measures. In Section 3.4, an axiom for the similarity measure on cubic intuitionistic fuzzy sets is introduced, various types of similarity measures are defined, and the relationship between the similarity and entropy measures on cubic intuitionistic fuzzy sets is investigated.

CHAPTER 4

Chapter 4 is organized into six sections. Section 4.1 introduces multi-criteria decision-making problems. Section 4.2 examines the use of various modal operators in multi-criteria decision-making, and Section 4.3 applies linguistic hedges in multi-criteria decision-making. Section 4.4 applies the cardinality measure and types of cardinalities, such as average possible

cardinality and relative possible cardinality, to multi-criteria decision-making problems on cubic intuitionistic fuzzy sets. Section 4.5 explores the application of various entropy measures on cubic intuitionistic fuzzy sets in multi-criteria decision-making. Section 4.6 applies different similarity measures on cubic intuitionistic fuzzy sets in multi-criteria decision-making using the TOPSIS method. Each section includes a comparative study between existing approaches and the proposed methods.

CHAPTER 5

Chapter 5 is organized into three sections. Section 5.1 provides a brief introduction to the chapter's content. In Section 5.2, the definition of cubic intuitionistic fuzzy image processing is formalized. In Section 5.3, an algorithm for image enhancement using contrast intensification operators on cubic intuitionistic fuzzy sets under P-order is developed, comparative studies are conducted among various extensions of fuzzy sets namely, intuitionistic fuzzy, interval-valued intuitionistic fuzzy, and cubic intuitionistic fuzzy sets using the intensification operator. Section 5.3 applies similarity measures on cubic intuitionistic fuzzy sets to an image recognition problem.

Summary and Conclusion

In this research, unified structures for calculating the cardinality, average possible cardinality, and relative cardinality on cubic intuitionistic fuzzy sets have been established.

A new framework for cubic intuitionistic fuzzy entropy has been developed as a generalization of both interval-valued intuitionistic fuzzy entropy and intuitionistic fuzzy entropy, along with different types of entropy measures. Additionally, a new definition of entropy for cubic intuitionistic fuzzy sets, based on distance, has been proposed. The applicability of this entropy measure is illustrated with numerical examples.

A similarity measure for cubic intuitionistic fuzzy sets is introduced, and various similarity measures are developed, along with a detailed exploration of the relationship between similarity and entropy measures. Several operators on cubic intuitionistic fuzzy sets are also defined, including $CON_P(\mathcal{A})$, $DIL_P(\mathcal{A})$, $INT_P(\mathcal{A})$ and $NORM_P(\mathcal{A})$ under P-order. Key properties of these operators are described, verified through numerical examples, and shown to facilitate the handling of imprecision and uncertainty by allowing for the combination, comparison, and modification of cubic intuitionistic fuzzy sets data.

To validate the effectiveness of the proposed measures and operators, these concepts are applied to a multi-criteria decision-making problem. A comparative study is conducted, highlighting the advantages of the cubic intuitionistic fuzzy sets over intuitionistic fuzzy sets and interval-valued intuitionistic fuzzy sets.

The concept of cubic intuitionistic fuzzy image processing is also formulated, demonstrating that contrast intensification operators within the framework of cubic intuitionistic fuzzy sets' can significantly enhance image quality, especially under P-order constraints. Additionally, similarity measures for cubic intuitionistic fuzzy sets are applied to image recognition problems, using MATLAB.

Results indicate that the operators and measures on intuitionistic fuzzy sets and interval-valued intuitionistic fuzzy sets lead to inconsistent rankings whereas they provide more precise outcomes on cubic intuitionistic fuzzy sets.

The future research directions based on this research work may be extended as follows:

1. The presented measures on cubic intuitionistic fuzzy sets can be utilized in morphological image processing.
2. The proposed operators can be used to define cubic intuitionistic fuzzy sets relation.
3. Cubic intuitionistic fuzzy sets can be applied to other image processing tasks, such as segmentation, edge detection, and etc.
4. Measures and operators on cubic intuitionistic fuzzy sets with R-order may be defined.

References

1. **Afsari, F., Eslami, E.** and **Eslami, P.,** Interval-valued intuitionistic fuzzy generators: Application to edge detection, Journal of Intelligent and Fuzzy Systems, 27(3), 2014, 1309-1324.
2. **Ananthi, V. P.** and **Balasubramaniam, P.,** Image fusion using interval-valued intuitionistic fuzzy sets, International Journal of Image and Data Fusion, 6(3), 2015, 249-269.
3. **Ananthi, V. P., Balasubramaniam, P.** and **Raveendran, P.,** A thresholding method based on interval-valued intuitionistic fuzzy sets: an application to image segmentation, Pattern Analysis and Applications, 21, 2018, 1039-1051.
4. **Atanassov, K.,** Intuitionistic fuzzy sets, Fuzzy Sets and Systems, 20, 1986, 87 – 96.
5. **Atanassov, K.,** Two intuitionistic fuzzy modal-level operators, Advances in Fuzzy Logic and Technology, 1(10), 2017, 85-98.
6. **Atanassov, K.,** On interval-valued intuitionistic fuzzy modal operators, Notes on Intuitionistic Fuzzy Sets, 24(1), 2018, 1-12.
7. **Atanassov, K.** and **Gargov, G.,** Interval – valued intuitionistic fuzzy sets, Fuzzy Sets and Systems, 31, 1989, 343-349.
8. **Bhattacharya, J.,** Some results on certain properties of intuitionistic fuzzy sets, Journal of Fuzzy Extension and Applications, 2(4), 2021, 377-387.
9. **Bu, F., He, J., Li, H.** and **Fu, Q.,** Interval-valued intuitionistic fuzzy MADM method based on TOPSIS and grey correlation analysis, Mathematical Biosciences and Engineering, 17(5), 2020, 5584-5603.
10. **Chamorro-Martínez, J., Sánchez, D., Soto-Hidalgo, J. M.** and **Martínez-Jiménez, P. M.**, A discussion on fuzzy cardinality and quantification, Some applications in image processing, Fuzzy Sets and Systems, 257, 2014, 85-101.
11. **Çitil, M.** and **Tuğrul, F.,** Some intuitionistic fuzzy operators, Notes on Intuitionistic Fuzzy Sets, 22(4), 2016, 1-5.
12. **Çitil, M.** and **Tuğrul, F.,** Some new equalities on the intuitionistic fuzzy modal operators, Sakarya University Journal of Science, 22(6), 2018, 1524-1531.
13. **Deng, H., Sun, X., Liu, M., Ye, C.** and **Zhou, X.,** Image enhancement based on intuitionistic fuzzy sets theory, IET Image Processing, 10(10), 2016, 701-709.
14. **Dhivya, J.** and **Sridevi, B.,** A New Similarity Measure between Intuitionistic Fuzzy Multisets based on their Cardinality with Applications to Pattern Recognition and

Medical Diagnosis, Asian Journal of Research in Social Sciences and Humanities, 7(3), 2017, 764-782.

15. **Ejegwa, P. A., Akowe, S. O., Otene, P. M.** and **Ikyule, J. M.,** An overview on intuitionistic fuzzy sets, International Journal of scientific & Technology Research, 3(3), 2014, 142-145.
16. **Eker, E., Tugrul, F.** and **Citil, M.,** New equalities on the intuitionistic fuzzy operators and operations, Notes on Intuitionistic Fuzzy Sets, 21(4), 2015, 124-128.
17. **Gao, M. M., Sun, T., Xu, R. P., Song, L.** and **Zhang, H. Q.,** An improved axiomatic definition and structural formula of interval-valued intuitionistic fuzzy entropy, Applied Mechanics and Materials, 644, 2014, 1556-1559.
18. **Garg, H.** and **Kaur, G.,** Novel distance measures for cubic intuitionistic fuzzy sets and their applications to pattern recognitions and medical diagnosis, Granular Computing, 5, 2018, 169-184.
19. **Garg, H.** and **Kaur, G.,** TOPSIS based on nonlinear-programming methodology for solving decision-making problems under cubic intuitionistic fuzzy set environment, Computational and Applied Mathematics, 38, 2019_a, 1-19.
20. **Garg, H.** and **Kaur, G.,** Cubic intuitionistic fuzzy sets and its fundamental properties, Journal of Multiple-Valued Logic and Soft Computing, 33(6), 2019_b, 507 - 537.
21. **Garg, H.** and **Kaur, G.,** Extended TOPSIS method for multi-criteria group decision-making problems under cubic intuitionistic fuzzy environment, Scientia Iranica, 27(1), 2020, 396-410.
22. **Gohain, B., Dutta, P., Gogoi, S.** and **Chutia, R.,** Construction and generation of distance and similarity measures for intuitionistic fuzzy sets and various applications, International Journal of Intelligent Systems, 36(12), 2021, 7805-7838.
23. **Guo, K.** and **Song, Q.,** On the entropy for Atanassov's intuitionistic fuzzy sets: An interpretation from the perspective of amount of knowledge, Applied Soft Computing, 24, 2014, 328-340.
24. **Guo, K.** and **Zang, J.,** Knowledge measure for interval-valued intuitionistic fuzzy sets and its application to decision making under uncertainty, Soft Computing, 23, 2019, 6967-6978.
25. **Hanmandlu, M.** and **Jha, D.** An optimal fuzzy system for colour image enhancement, IEEE Transactions on Image Processing, 15, 2006, 2956-2966.

26. **Hu, K.** and **Li, J.,** The entropy and similarity measure of interval-valued intuitionistic fuzzy sets and their relationship, International Journal of Fuzzy Systems, 15(3), 2013, 279-288.
27. **Ibrahim, A. M.** and **Ejegwa, P. A.,** Remark on some operations of intuitionistic fuzzy sets, International Journal of Science and Technology, 2(1), 2013, 94-96.
28. **Jing, L.,** Entropy and similarity measures for interval-valued intuitionistic fuzzy sets based on intuitionism and fuzziness, Advanced Modelling and Optimization, 15(3), 2013, 635-643.
29. **Jun, Y. B., Kim, C. S** and **Yang, K. O.,** Cubic sets, Annals of Fuzzy Mathematics and Informatics, 4, 2012, 83-98.
30. **Kaur, G.** and **Garg, H.,** Cubic intuitionistic fuzzy aggregation operators, International Journal for Uncertainty Quantification, 8(5), 2018, 405-427.
31. **Kokoc, M.** and **Ersoz, S.,** A comparison of the performance of entropy measures for interval-valued intuitionistic fuzzy sets, Sigma Journal of Engineering and Natural Sciences, 39(2), 2021,131-147.
32. **Li, J., Deng, G., Li, H.** and **Zeng, W.,** The relationship between similarity measure and entropy of intuitionistic fuzzy sets, Information Sciences, 188, 2012, 314-321.
33. **Liu, M.** and **Ren, H.,** A new intuitionistic fuzzy entropy and application in multi-attribute decision making, Information, 5, 2014, 587 – 601.
34. **Luo, L.** and **Ren, H.,** A new similarity measure of intuitionistic fuzzy set and application in MADM problem, AMSE Journals – Series: Advances A, 59, 2016, 204-223.
35. **Mala, S. K.** and **Shanmugapriya, M. M.,** Properties of intuitionistic fuzzy set operators, International Journal of Development Research, 7(7), 2017, 13760-13763.
36. **Mamoni Dhar,** Cardinality of fuzzy sets: An overview, International Journal of Energy, Information and Communications, 4(1), 2013, 15-20.
37. **Meng, F.** and **Chen, X.,** Entropy and similarity measure for Atannasov's interval-valued intuitionistic fuzzy sets and their application, Fuzzy Optimization and Decision Making, 15(1), 2015, 75-101.
38. **Mohamed A. El-Sayed,** New Similarity measure of fuzzy sets for face recognition in image sets, Advances in Computer Science and Engineering, 11(1), 2013, 1-19.
39. **Mohamed, S. S., Abdalla, A.** and **John, R. I.,** New entropy-based similarity measure between interval-valued intuitionistic fuzzy sets, Axioms, 8(73), 2019, 1-11.

40. **Mohammed Nabeel Iqbal,** Some topological and modal operators over the intuitionistic fuzzy sets of cube root type. International Journal of Recent Technology and Engineering, 8(3), 2019, 1247-1251.
41. **Ohlan, A.,** Novel entropy and distance measures for interval-valued intuitionistic fuzzy sets with application in multi-criteria group decision-making, International Journal of General Systems, 51(4), 2022, 413-440.
42. **Palaniappan, N.** and **Srinivasan, R.,** Applications of intuitionistic fuzzy sets of root type in image processing, Annual Meeting of the North American Fuzzy Information Processing Society, IEEE, 2009, 1-5.
43. **Park, J. H., Lim, K. M., Kwun, Y. C.** and **Son, M. J.,** Entropy and similarity measure of interval-valued intuitionistic fuzzy sets, Proceeding of KFIS Autumn Conference, 17(2), 2007_a, 187-190.
44. **Park, J. H., Lim, K. M., Kwun, Y. C.** and **Son, M. J.,** Subsethood measure and entropy of interval-valued intuitionistic fuzzy sets, Proceeding of KFIS Autumn Conference, 17(2), 2007_b, 362-365.
45. **Parvathi, R., Kuppannan, J. Atanassov, K.** and **Gluhchev, G.,** Role of fuzzy and intuitionistic fuzzy contrast intensification operators in enhancing images, Notes on Intuitionistic Fuzzy Sets, 14, 2008, 59-66.
46. **Patel, A., Jana, S.** and **Mahanta, J.,** Construction of similarity measure for intuitionistic fuzzy sets and its application in face recognition and software quality evaluation, Expert Systems with Applications, 237, 2024, 1-25.
47. **Rashid, T., Faizi, S.** and **Zafar, S.,** Distance based entropy measure of interval-valued intuitionistic fuzzy sets and its application in multicriteria decision making, Advances in Fuzzy Systems, 2018, 1-10.
48. **Satapathy, M. K.,** A bag theoretic approach towards the count of an intuitionistic fuzzy set, International Journal of Intelligent Systems Technologies and Applications, 5, 2015, 16-23.
49. **Selvachandran, G.** and **Salleh, A. R.,** Intuitionistic fuzzy linguistic variables, and intuitionistic fuzzy hedges, Far East Journal of Mathematical Sciences, 95(2), 2014, 221-233.
50. **Sharma, P. K.,** Modal operator $F_{\alpha,\beta}$ in intuitionistic fuzzy groups, Annals of Pure and Applied Mathematics, 7(1), 2014, 19-28.

51. **Singh, A.** and **Kumar, S.,** A novel dice similarity measure for IFSs and its applications in pattern and face recognition, Expert Systems with Applications, 149, 2020, 1-30.
52. **Song, Y., Wang, X., Quan, W.** and **Huang, W.,** A new approach to construct similarity measure for intuitionistic fuzzy sets, Soft Computing, 23(6), 2019, 1985-1998.
53. **Sun, M.** and **Liu, J.,** New entropy and similarity measures for interval-valued intuitionistic fuzzy set, Journal of Information and Computational Sciences, 9(18), 2012, 5799-5806.
54. **Talukdar, P.** and **Dutta, P.,** An Advanced Entropy Measure of IFSs via Similarity Measure, International Journal of Fuzzy System Applications, 12(1), 2023, 1-23.
55. **Thao, N. X.** and **Chou, S. Y.,** Novel similarity measures, entropy of intuitionistic fuzzy sets and their application in software quality evaluation, Soft Computing, 26, 2022, 1-12.
56. **Tiwari, P.** and **Gupta, P.,** Entropy distance and similarity measures under interval-valued intuitionistic fuzzy environment, Informatica, 42(4), 2018, 617-627.
57. **Tripathy, B. K., Jenab, S. P.** and **Ghosh, S. K.,** An Intuitionistic fuzzy count and cardinality of Intuitionistic fuzzy sets, Malaya Journal of Matematik, 4(1), 2013_a, 123-133.
58. **Tripathy, B. K., Saraf, P.** and **Satapathy, M. K.,** On intuitionistic fuzzy measures and the count of intuitionistic fuzzy sets, IEEE International Conference on Computational Intelligence and Computing Research, 2013_b,1-4.
59. **Verma, R.** and **Sharma, B. D.,** Exponential entropy on intuitionistic fuzzy sets, Kybernetika, 49(1), 2013, 114-127.
60. **Verma, R.** and **Sharma B. D.,** On intuitionistic fuzzy entropy of order – α, Advances in Fuzzy Systems, 2014, 1-8.
61. **Vlachos, I. K.** and **Sergiadis, G. D.,** Intuitionistic fuzzy image processing, Soft Computing in Image Processing: Recent Advances, 2007, 383-414.
62. **Wei, C. P., Wang, P.** and **Zhang, Y. Z.,** Entropy, similarity measure of interval-valued intuitionistic fuzzy sets and their applications, Information Sciences, 181(19), 2011, 4273-4286.
63. **Wu, C., Luo, P., Li, Y.** and **Ren, X.,** A new similarity measure of interval-valued intuitionistic fuzzy sets considering its hesitancy degree and applications in expert systems, Mathematical Problems in Engineering, (1), 2014, 1-16.

64. **Xie, B., Han, L. W.** and **Mi, J. S.,** Measuring inclusion, similarity and compatibility between Atanassov's intuitionistic fuzzy sets, International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 20(02), 2012, 261-280.

65. **Xu, Z.** and **Zhao, N.,** Entropy measures for interval-valued intuitionistic fuzzy information from a comparative perspective and their application to decision making, Informatica, 27(1), 2016, 203-228.

66. **Ye, J.,** Interval-valued intuitionistic fuzzy cosine similarity measures for multiple attribute decision-making, International Journal of General Systems,42(8), 2013, 883-891.

67. **Yu, B., Zhao, X., Zheng, M., Yuan, X.** and **Hou, B.,** Entropy on intuitionistic fuzzy sets and hesitant fuzzy sets, Journal of Mathematics, 2022, 1-10.

68. **Yuan, X.** and **Zheng, C.,** Improved intuitionistic fuzzy entropy and its application in the evaluation of regional collaborative innovation capability, Sustainability, 14(5), 2022, 1-14.

69. **Zadeh, L. A.,** Fuzzy sets, Information and control, 8, 1965, 338-353.

70. **Zhang, Q. S.** and **Jiang, S. Y.,** Relationships between entropy and similarity measure of interval-valued intuitionistic fuzzy sets, International Journal of Intelligent Systems, 25(11), 2010_a, 1121-1140.

71. **Zhang, Q. S., Jiang, S., Jia, B.** and **Luo, S.,** Some information measures for interval-valued intuitionistic fuzzy sets, Information sciences, 180(24), 2010_b, 5130-5145.

72. **Zhang, Q., Xing, H.** and **Wu, L.,** Entropy, similarity measure, inclusion measure of intuitionistic fuzzy sets and their relationships, International Journal of Computational Intelligence Systems, 5(3), 2012_a, 519-529.

73. **Zhang, Q., Liu, F., Wu, L.** and **Luo, S.,** Information entropy, similarity measure and inclusion measure of intuitionistic fuzzy sets, Information Computing and Applications: Third International Conference, ICICA, Chengde, China, 2012_b, 392-398.

74. **Zhang, Q., Xing, H., Liu, F., Ye, J.** and **Tang, P.,** Some new entropy measures for interval-valued intuitionistic fuzzy sets based on distances and their relationships with similarity and inclusion measures, Information Sciences, 283, 2014, 55-69.

Publications

1. **Priyadharshini, M., Jayanthi, D.** and **Saranya, M.,** Cardinality and relative cardinality on cubic intuitionistic fuzzy sets, International Journal of Information Technology (Singapore), 2024, 16(4), 4059-4068.
2. **Priyadharshini, M., Jayanthi, D.** and **Saranya, M.,** New operations on cubic intuitionistic fuzzy sets under P-order, Journal of Fuzzy Extension and Applications, 2024 (accepted).
3. **Priyadharshini, M., Jayanthi, D.** and **Saranya, M.,** Similarity measures on cubic intuitionistic fuzzy sets (under revision).
4. **Priyadharshini, M.** and **Jayanthi, D.,** Entropy Measure on cubic intuitionistic fuzzy sets (communicated).
5. **Priyadharshini, M., Jayanthi, D.** and **Parvathi, R.,** Cubic intuitionistic fuzzy image processing (communicated).